Elasticity Influence On the Break-up of Coalescent Opposed Jets Immersed in a Viscous Liquid

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1. Introduction

The coalescence of immersed jets in a surrounding medium other than air is still a subject under investigations. The understanding and modeling of this phenomenon leads to applications not only in the area of extensional and interfacial rheometry [1], but also in the control of mixing and transfer processes between threads of immiscible liquids [2]. The present experimental study is focused on the elasticity influence on the opposed jets immersed in a Newtonian mineral oil. The experiments take place at low Reynolds and Capillary numbers and follow to establish a correlation between the shape of the liquid bridge in the coalescence area and the break-up length of the down-stream jet. Weakly elastic polymer solutions and water-glycerin mixtures at same viscosity were used as samples, in order to emphasize the elastic effects. The length of the thread connecting the pendant droplet at the moment of break-up is theoretically predicted.

2. Theoretical aspects and experiments

The tendency of elasticity to destabilize the interface between immiscible liquids is investigated by comparing jets coalescence of viscoelastic fluids with Newtonian ones. For weakly elastic polymer solutions, Fig. 1a, the stability and break-up of the viscoelastic thread is studied in correlation with the upstream coalescence of two symmetrical jets immersed in a pure viscous fluid.

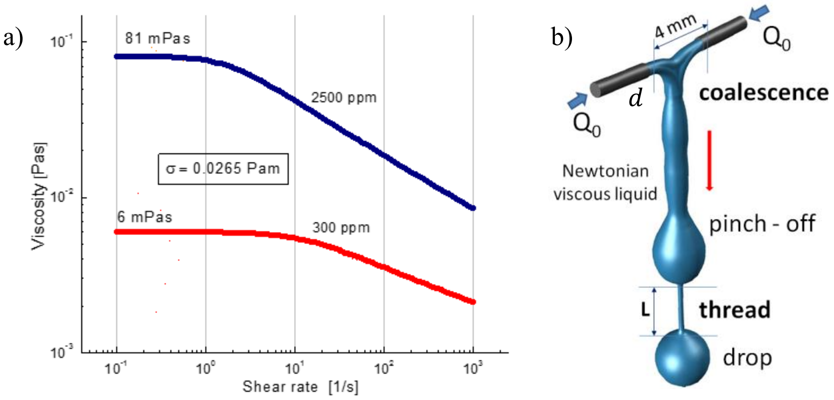

Fig.1. (a) Viscosity function of the tested polymer solutions and their interfacial tension in the immersed Newtonian fluid; (b) Sketch of the coalescence and the breakup of the viscoelastic thread in a viscous liquid.

The non-dimensional parameters that characterize the phenomenon are Reynolds, Weissenberg and Capillary numbers: $\mathcal{R}e = \rho v_0 d/\eta$, $\mathcal{W}i = \lambda v_0/R$, $\mathcal{C}a = \eta v_0/\sigma$, together with the viscosity and the density ratio: η/η_{oil}, ρ/ρ_{oil}. Here ρ, η, σ, λ are the properties of the viscoelastic fluid filament (density, viscosity, interfacial tension and relaxation time, respectively). The filament of radius R is emerged from the cylindrical nozzles of diameter $d = 0.84\ mm$ with the average velocity v_0.

Threads of different patterns, pendant droplets, beads-on-a-string structures on immersed filament are generated at particular flow rates by the presence of elasticity, Fig. 2. The radius R of the elastic uniform thread decreases exponentially in time (Eq.1a) and filament break-up occurs at time t_c (Eq.1b) [3]. From the equilibrium of forces that act on the thread (Eq. 2a), Fig. 2a, the droplet acceleration (Eq.2b) is derived, where C_1 and C_2 are constants dependent of the material properties, the initial radius of the filament R_o and the diameter D_p of the pendant drop of velocity v and volume ϑ. Finally, a relation for the break-up length L of the filament is proposed (Eq. 2c, Fig. 1b and Fig.2a).

$$\frac{R(t)}{R_o} = \sqrt[3]{\frac{GR_o}{2\sigma}}\, e^{\left(-\frac{t}{3\lambda}\right)} \ \text{(a)}, \quad t_c = 3\lambda \, ln\left[\frac{4}{3}L^2\left(\frac{GR_o}{\sigma}\right)^{\frac{4}{3}}\right] \ \text{(b)} \qquad (1)$$

$$\Delta\rho\vartheta g - 2\pi R(t)\sigma = 3\pi\eta_{oil}D_p v + \rho\vartheta dv/dt \ \text{(a)}, \ a = C_1 - C_2 Exp[-t/3\lambda] \ \text{(b)}, \ L = at_c^2/2 \ \text{(c)} \qquad (2)$$

A system with two needles was used to study the colliding of identical immersed opposed jets (identical flow rates Q_0 were discharged through the needles from a double syringe pump, Fig. 1b). The samples are weakly elastic polyacrylamide solutions (PAM 300 ppm and PAM 2500 ppm, Fig. 1a) and solutions of glycerol in water (WG1 and WG2) with viscosities: $\eta_1 = 0.006\ Pas$ and $\eta_2 = 0.081\ Pas$ (where $\rho_{oil} = 910\ \ kg/m^3$ and $\eta_{oil} = 55mPas$). A Nikon J5 camera with 3840×2160 resolution at 400 frames/s captures the phenomenon. The experimental flow patterns (Fig. 2b) and the dynamics of the threads at two imposed flow rates (Fig. 2c) are analyzed.

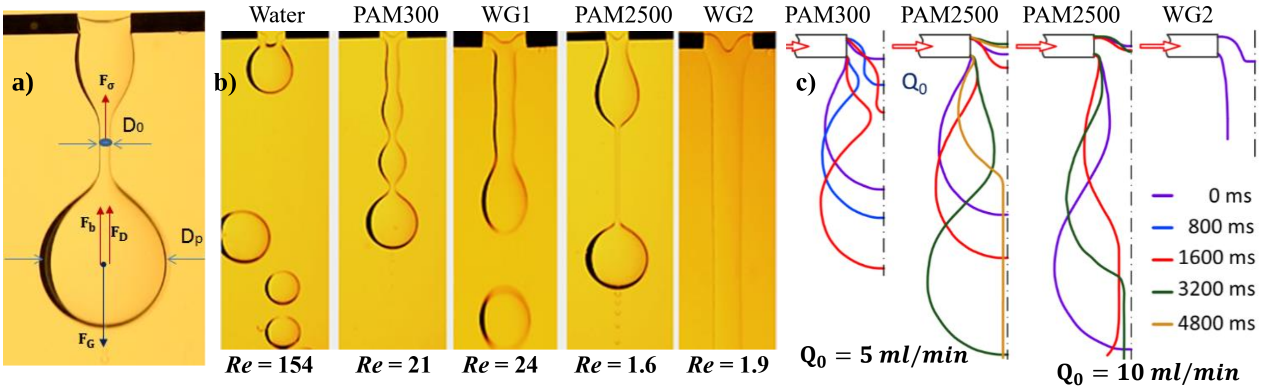

Fig. 2. (a) Forces on droplet before break-up; (b) Opposed jets patterns at $Q_0 = 10ml/min$, (c) Evolutions of the threads in time at constant input flow rates $Q_0 = 5\ ml/min$ and $Q_0 = 10\ ml/min$ (for PAM2500 the parameters are: $\mathcal{Re} = 1.6$, $\mathcal{Ca} = 0.95$, $\mathcal{Wi} = 3.6$ with $\eta = \ 81mPas$, $\sigma = \ 25.6mN/m$, $\lambda = \ 5ms$, $\rho = 1190kg/m^3$; the predicted break-up length from Eq. 2c is $L = 36\ mm$, slightly lower in comparison with the experimental length of 38 mm).

5. Conclusions

The study emphasizes the influence of elasticity on a coalescent mass of the immersed opposed jets at low Reynolds numbers and moderate Capillary numbers. The maximum observed curvature of the meniscus (liquid bridge) formed between the needles is recorded for the weakly elastic PAM300 solution at $\mathrm{Q}_0 = 5\ ml/min$ (Fig. 2c). In the case of PAM 2500, due to high viscosity and increased elasticity, the coalescent mass of fluid forms a more stable liquid bridge, from which the droplets with long filaments are formed. A steady meniscus and filament is recorded for the Newtonian WG2 solution, in comparison with the corresponding PAM2500 jet, which discloses due to elasticity high oscillations at small flow rate, as the breakup occurs.

The target for the further work is to establish the correlation between the shape of meniscus at jets coalescence, flow rate and the fluids properties, in order to predict the break-up length of the immersed jets filaments by recording the liquid bridge oscillations.

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